ELECTROMYOGRAPHIC STUDIES ON THE VISCERO-MOTOR REFLEXES

by

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Contents

I INTRODUCTION

Stimulation of the abdominal viscera evokes various reflexes such as viscero-motor reflex, viscero-sensible reflex, viscero-viscero reflex and so on.

The viscero-motor reflex, clinically proved as "défense musculaire", is of great interest for a surgeon, and many investigations have been made by experiments on animals as well as by clinical observations.

The first description was made by MACKENZIE and SHERRINGTON (1906), who observed the abdominal muscles contract by a stimulation given to the bile duct or the central end of the superior mesenteric nerve. Then, MILLER and SIMPSON (1924), in their animal experiments, found that mechanical, chemical and electrical stimulation of the abdominal viscera or the sympathetic nerves produced contraction of the leg and belly muscles. DOWNMAN and McSWINEY (1946) reported that limb movements and blood pressure responses were elicited by stimulating not only the intestine but also the peritoneum and nearly all of the organs of the abdomen by pinching, pulling or faradizing. Almost the same result was reported by EULER and SJÖSTRAND (1947). They showed that the viscero-motor reflex can be elicited from the intestinal wall by mechanical, electrical, chemical and thermal stimuli without the involvement of the mesentery or of its connection with the intestine.

On the contrary, LEWIS and KELLGREN (1939) maintained that they could never elicit responses from the solid organs, such as kidney, spleen, liver, and from any part of the stomach or bowel. They could only prove the reflex by stimulating structures lying in the mesentery of the duodenal loop (pancreas, etc.).

Recently, WATANABE (1954) who studied the viscero-motor reflex using the mechano-myographic method, proved that the visceral afferent nerves run into the spinal cord at the same sites as the motor roots of the rectus muscles.

The reflex has also been studied by several investigators from the respects of action potentials of the nerve fibers. GERNANDT and ZOTTERMAN (1947) recorded afferent impulses of the splanchinic and mesenteric nerves. DOWNMAN (1955) found that maximal single-shock stimulation of splanchnic nerve evoked reflex volleys in intercostal, lumbar, and leg nerves.

Clinical studies of "défense musculaire", likewise, have been reported by many investigators. TSUSHIMA (1952), NANJO (1954) and SHIRATORI (1958) made researches in that department in the patients of peritonitis and other abdominal diseases by electromyographic method.

The purpose of the present investigation is to record the action potentials (electromyogram: EMG) of the abdominal wall muscles elicited by noxious stimulation of the abdominal viscera, and thereby to clarify the relationship of nerve innervations between the abdominal viscera and abdominal wall muscles, inter alia, from the metameric point of view.

II METHODS

Experimental animals

Cats were used in all experiments. Under preliminary ether anesthesia, and after ligating the common carotid arteries, the animal was decerebrated by transection of the brain stem at the level of the MAGNUS's 2nd section. Usually recording of EMG was begun 30 min. after decerebration in order to avoid an acute decerebrated shock.

Recording

An EDISWAN 8-channel electroencephalograph was used, and all the records were obtained with the ink-writer oscillographs incorporated in the machine.

With surface electrodes which were placed on the abdominal wall muscles, eight EMG's were recorded simultaneously not only from the different muscles, e. g., the rectus abdominis, the external oblique, the internal oblique, and transversalis muscle, but also from different parts of the same muscles, e. g., eight parts of the rectus abdominis.

Stmulation

Chemical stimulus was given by acetylcholine (ACh) solution at concentration of 0.1 gm per 50 to 100 cc of physiologic salt solution. In most cases, 0.1 to 0.5 cc of its solution were used.

For electrical stimulation, an isolated output stimulator (Nihon Koden & Co. Ltd.) was employed which delivered a monophasic square wave. The characteristics of electrical stimulation used in this experiment were as follows: 60 to 200 cycles per second, 0.1 to 0.5 milliseconds pulse duration, and 1 to 40 volts. The duration of each stimulation was 10 to 30 seconds. Stimulating electrodes were concentric needle electrodes, center pole of which was used as anode.

III RESULTS

(1) *Responses of rectus abdominis to the stimulation of the abdominal viscera*

Ten surface electrodes were symmetrically placed on the right and left rectus abdominis (Fig. 1), then laparotomy was performed at the midline. The celiac artery was exposed at its origin and therein ACh solution was injected in about 5

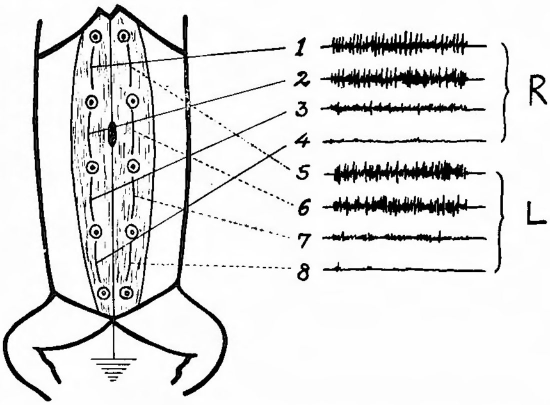
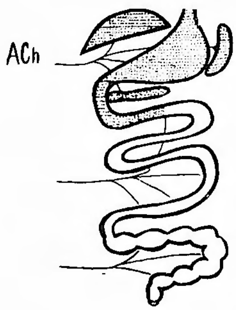


Fig. 1 shows the placing of electrodes on the rectus abdominis and the order of EMG's corresponding with eight parts of the right and left rectus muscles. For convenience, recording numbers, 1 to 8, are used. In following all figures the order (1 to 8) are the same as in this Figure. R: right rectus abdominis. L: left rectus abdominis. ◎: electrodes.



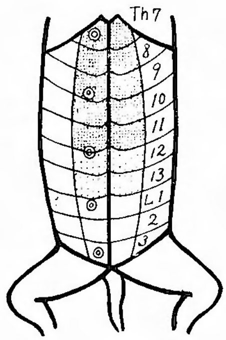


Fig. 2-A. Fig. 2-B.

Fig. 2-A shows the distributed area of ACh solution which was injected into the celiac artery. The area include the upper abdominal viscera: stomach, pancreas, liver, and duodenum, as represented by stippling. ACh : acetylcholine solution

Fig. 2-B shows the main segments of dermatomes (densely stippling) reflected from the upper abdominal viecera. These segments (Th 7 to Th 11) are decided by the pattern of EMG's of Fig. 3. Th: thoracic segment. L: lumbar segment. ◎: electrodes.

seconds. Usually muscular contractions became evident within 3 to 5 seconds after the beginning of the injection and well developed at the following period. The duration of the response varied from 20 seconds in some animals to 2 minutes in others. These muscular effects were recorded on EMG throughout. In this experiment, distributed region of ACh solution included all upper abdominal viscera such as stomach, pancreas, liver, and duodenum (Fig. 2-A). Fig. 3 gives the typical EMG's obtained by stimulating those viscera. They show high frequency and wide amplitude of spike discharge in the upper part of rectus muscle, mainly in Th 7 to Th 11 segments of dermatome of abdominal wall. The result is illustrated in Fig. 2-B.

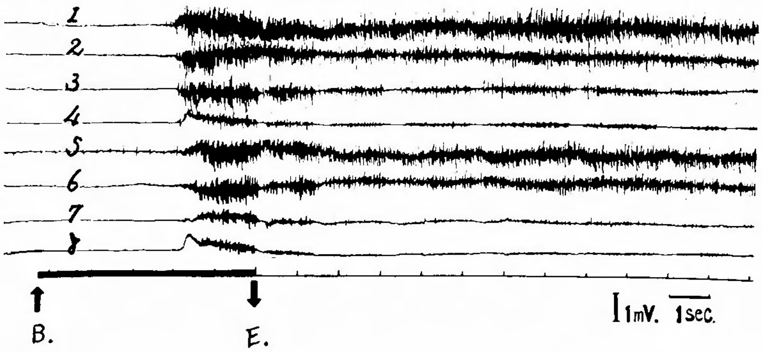


Fig. 3 EMG's of the rectus abdominis which were recorded by stimulating the upper abdominal viscera. Records 1 and 2 show the EMG's of upper part of right rectus and also Records 5 and 6 show ones of the left side. In these records the remarkable discharges are observed. B: beginning of injection of ACh E: end of injection: In all subsequent figures, B and E are the same as in this figures.

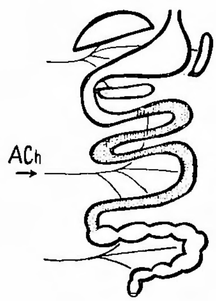


Fig. 4-A.

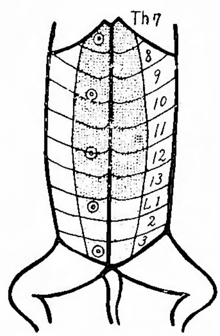


Fig. 4-B.

Fig. 4-A shows the distributed area of ACh solution injected into the superior mesenteric artery at arrow. Stippling, represents the area, the small intestine.

Fig. 4-B shows the main segments (densely stippling) reflected from the intestine. These segments (Th 7 to Th 13) are decided by the pattern of the EMG's of Fig. 5.

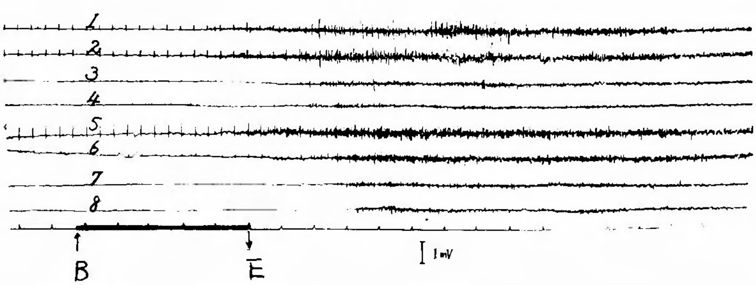
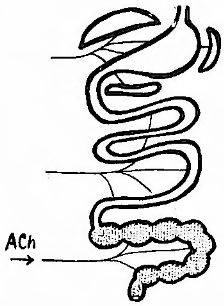


Fig. 5 EMG's of the rectus abdominis when the small intestine was stimulated. Records 1, 2, 3, 5, 6, and 7 show the notable spike discharges.



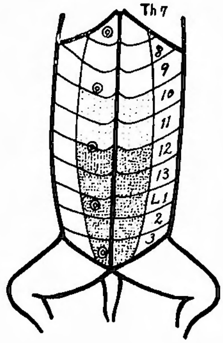


Fig. 6-A. Fig. 6-B.

Fig. 6-A shows the distributed area of ACh solution injected into the inferior mesenteric artery at arrow. Stippling represents the area, the colon.

Fig. 6-B shows the main segments (densely stippling) reflected from the colon. These segments (Th 12 to L_3) are decided by the pattern of EMG's of Fig. 7.

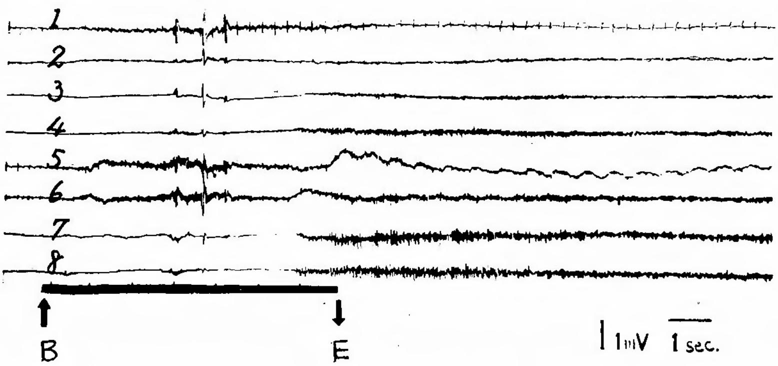


Fig. 7 EMG's of the rectus muscle when the colon was stumulated. Records 3 and 4 (from right rectus abdominis) and Records 7 and 8 (from left rectus abdominis) show the notable spike discharges.

Using the same method, ACh solution was injected into the superior mesenteric artery. In this occasion, the solution was distributed into the whole small intestine except for the duodenum (Fig. 4-A). The EMG's are shown in Fig. 5. Marked spike discharges are observed at the upper and middle parts of the rectus muscle, i. e., Th 7 to Th 13 segments of dermatome. Fig. 4-B is a schematic illustration of corresponding dermatome to the EMG's.

Further investigation was made by injecting ACh solution into the inferior mesenteric artery supplying the lower alimentary canal (Fig. 6-A). The EMG's are given in Fig. 7. The spike discharges are remarkable at the middle and lower parts of the rectus muscle, i. e., in Th 12 to L 3 segments of dermatome. The result is illustrated as Fig. 6-B.

(2) *Relationship between the viscero-motor reflexes and the intestinal contraction*

Intestinal movements were recorded on a kymogram by the balloon method, in which the balloon was inserted into decerebrated cat's intestine. On the other hand,

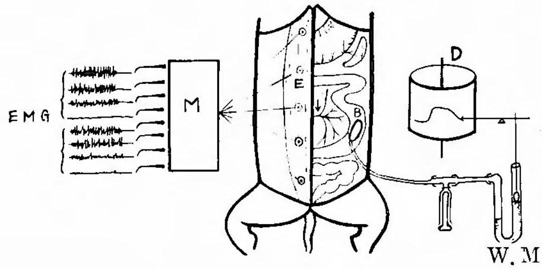


Fig. 8 Diagram of experimental method for studing the relationship between the intestinal spasm and the abdominal wall muscle contraction. Recording of intestinal spasm: A rubber balloon (B) is connected via the rubber tubing to a water manometer (W. M) supporting a float and a writing point which records on a moving smoked drum (D). The balloon is inserted into the intestine. Thus, intestinal movement is represented on a kymogram as a change of internal pressure of intestine. Recording of abdominal muscle contraction: For description see text. (E) electrodes, (M) electromyograph, (EMG) eight electromyograms of rectus abdominis. Stimulation: ACh solution was injected into the superior mesenteric artery at allow.

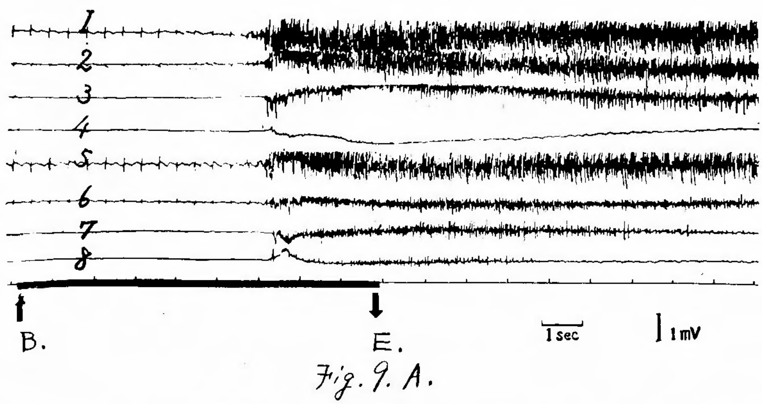


Fig. 9-A Muscle-action potentials of the rectus abdominis elicited by injection of ACh solution into the superior mesenteric artery. Note the beginning of discharges. They developed during the injection of ACh 6 seconds after the start of the injection. At this time, was not proved the distinct intestinal contraction. Compare with mark A of Fig. 10.

synchronous recording of the EMG's of the rectus muscle was carried out by the same method as above described (Fig. 8).

By injecting ACh solution into the superior mesenteric artery, vigorous spasm of the intestine were observed, associated with powerful contraction of the rectus abdominis. As shown in Figs. 9 and 10, the spike discharges of rectus muscle began prior to the contraction of intestine, and 2 minutes later the former discharges already ceased in spite of the latter contraction going on. Fig. 11 is the schematic illustration showing the relation of these phenomena.

Under the same condition, the physiological salt solution was injected. No discharge was recorded from the abdominal muscle.

After stopping the blood flow by means of ligating the superior mesenteric

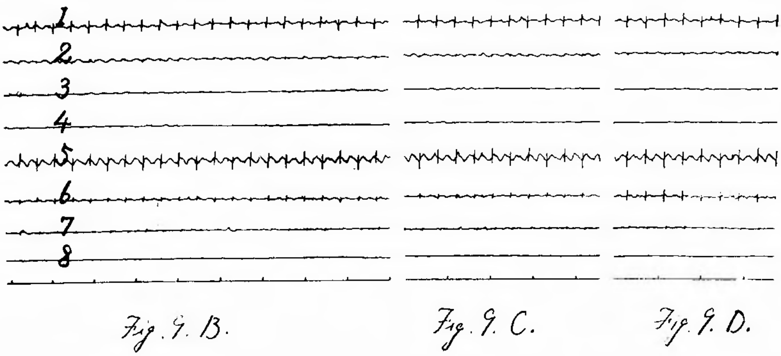


Fig. 9-B Two minutes after the injection. Corresponding with stage of powerful contraction of intestine (mark B of Fig. 10).

Fig. 9-C Corresponding with stage of release of intestinal contraction (mark C of Fig. 10).

Fig. 9-D Corresponding with stage of perfect relaxation of intestine. (mark D of Fig. 10). In each stage (B, C, D), no action potentials were recorded from the rectus muscle. The electrocardiograms were only given.

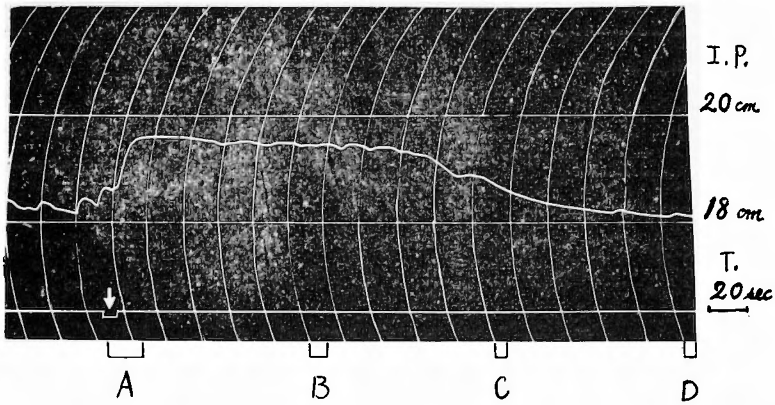


Fig. 10 Kymogram of the intestinal contraction. A, B, C, D correspond with those of Fig. 9. See account of Fig. 9. Arrow: injection of ACh solution. I. P.: internal pressure of the intestine (water manometer, cm.). T: time.

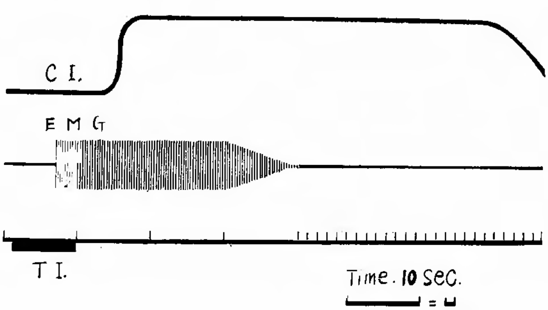


Fig. 11 Schematic illustration of EMG's in Fig. 9 (-A,-B,-C,-D) and kymogram in Fig. 10. See text and accounts of Fig. 9 and 10. C. I.: contration of intestine. EMG: electromyogram of rectus abdominis. T. I.: time of injection.

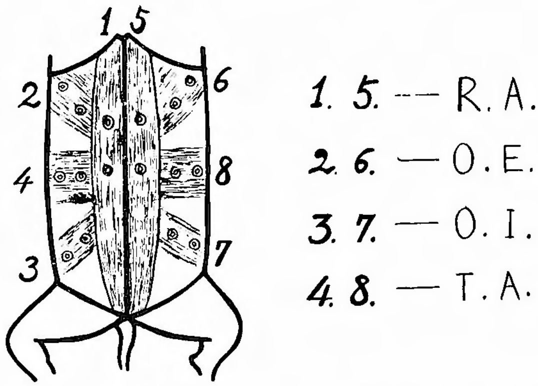


Fig. 12 Showing the placing of electrodes on the whole anterior abdonimal muscles. Numbers given to each muscle correspond with recording numbers of EMG's in Fig. 13. R. A.: rectus abdominis. O. E.: obliquus externus. O. I.: obliquus internus. T. A.: transversus abdominis.

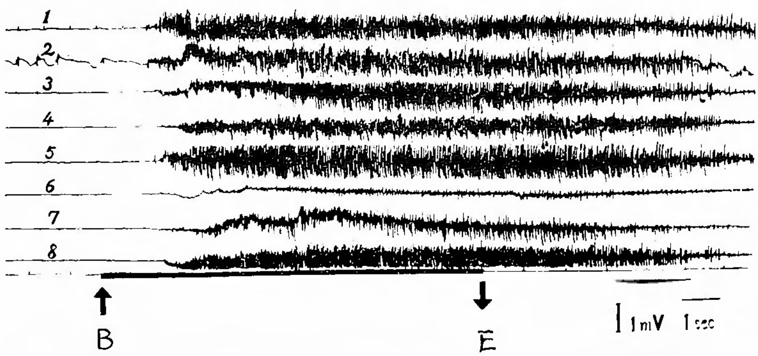


Fig. 13 EMG's of whole anterior abdominal wall muscles. 1.5.: EMG's of rectus abdominis. 2.6.: obliquus externus. 3.7.: obliquus internus. 4.8.: transversus abdominis.

artery and its branches, ACh solution was injected into the artery at the proximal site to ligation. In this occasion, likewise, no discharge occurred.

(3) *Simultaneous observation on the four abdominal muscles*

The surface electrodes were placed on the external oblique, the internal oblique, the transversalis, and the rectus abdominis, in both right and left sides respectively (Fig. 12). As shown in Fig. 13, the action potentials were recorded from each muscle by the injection of ACh into the superior mesenteric artery.

(4) *Responses to the stimulation of the uterus*

ACh solution was injected into the left uterine artery of a pregnant cat. Fig. 14 shows the periodic spike discharges in the lower part of left rectus abdominis, associated with the contraction of the uterus of the corresponding side.

(5) *Responses to the stimulation of the abdominal visceral arteries*

Three main vessels, viz., celiac, superior mesenteric, and inferior mesenteric arteries were examined. Stimulation were effected through the isolated out-put stimulator and the concentric needle electrodes giving the square wave currents. For

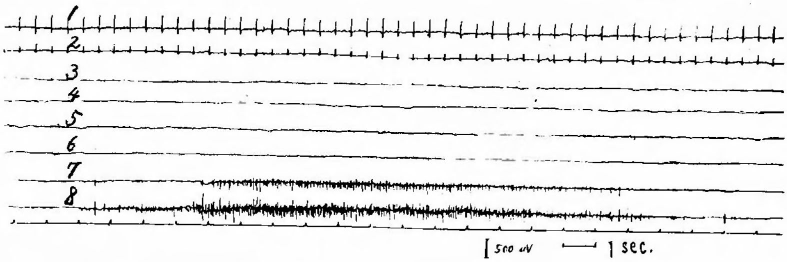


Fig. 14 EMG's of the rectus .abdominis which were recorded by stimulating the uterus. Showing one period of them, 2 minutes after injection of ACH. Note the remarkable discharges in Records 7 and 8.

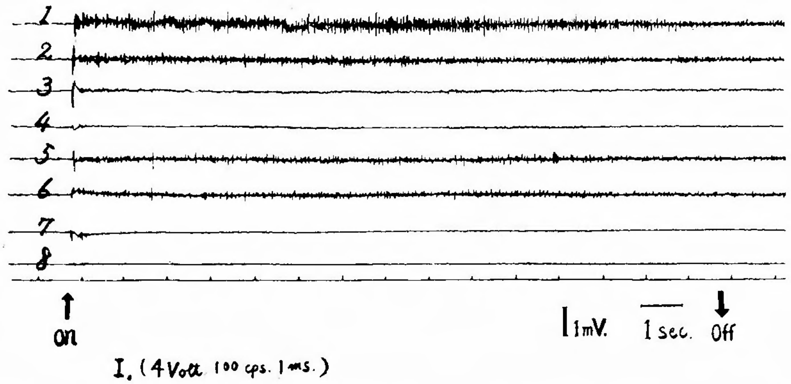


Fig. 15 EMG's of the rectus abdominis obtained by stimulating the celiac artery. Records 1, 2, 5, and 6 show the notable spike discharges. On: onset of electrical stimulation. Off: end of the stimulation. I: intensity of stimuli.

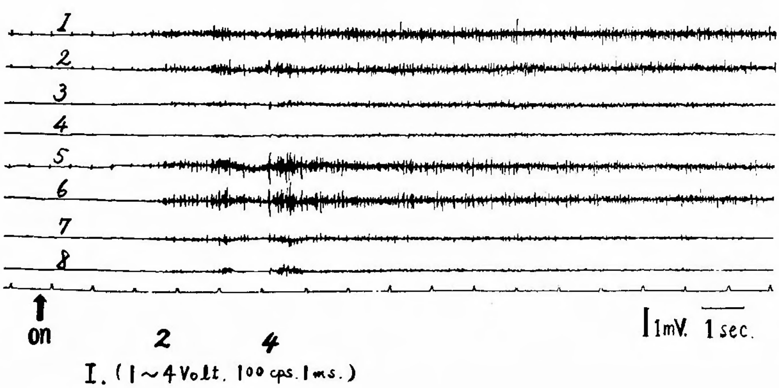


Fig. 16 EMG's of the rectus abdominis, obtained by stimulating the superior mesenteric artery. Notable discharges in Records 1, 2, 5, and 6, and appreciable discharges in Records 3 and 4 are observed. On and I: the same as in Fig. 15.

the recording of the EMG's of the abdominal muscle, almost the same method as above described was employed except for the use of a piece of vinyl sheet in order to avoid the effect of leak currents.

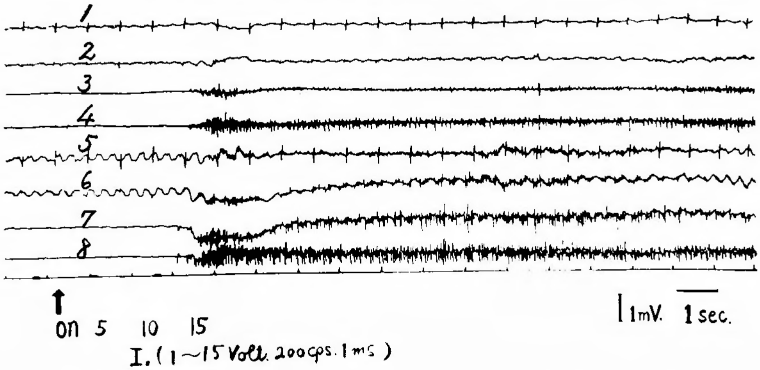


Fig. 17 EMG's of the rectus abdominis obtained by stimulating the inferior mesenteric artery. Note the remarkable discharges in Records 3, 4, 7, and 8. On and I: the same as in Fig. 15.

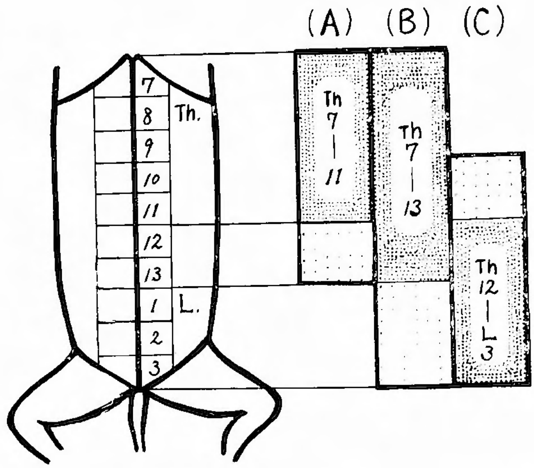


Fig. 18 shows the segments of "défense musculaire" corresponding with upper, middle, and lower abdominal viscera respectively. Fig. 2-B, Fig. 4-B, and Fig. 6-B are summarized in this figur. (A) Th7-Th11: reflected from the stomach, pancreas, liver, and duodenum. (B) Th7-Th13: from jejunum and ileum. (C) Th12-L3: from colon and rectum. Densely stippling: main segments. Thinly stippling: border segments.

Fig. 15 is the EMG's of the rectus muscle recorded by the electrical stimulation of the celiac artery. The notable discharges are shown at the upper part of the muscle, i. e., at Th 7 to Th 11 segments of dermatome.

The result obtained from the superior mesenteric artery is given in Fig. 16, which exhibits the remarkable discharges at the upper and middle parts of the muscle, i. e., Th 7 to Th 13 segments.

The responses from the inferior mesenteric artery are shown in Fig. 17. The spike discharges are mainly observed at middle and lower parts of the muscle, i. e., from Th 12 to L 3 segments.

IV DISCUSSION

Various methods have been employed for recording muscular contraction resulted from viscero-motor reflexes. MILLER and other investigators used the mechano-myographic methods. DOWNMAN and others observed the contraction with naked eyes or by palpation only. Recently, electromyographic method has been introduced into the research of the neuro-muscular system. By this method, TSUSHIMA, EULER and SJÖSTRAND have reported some valuable experiments on the viscero-motor reflex. The present author also adopted this new method, since the classical one was not only uncertain but also non-physiologic.

In addition, the electromyographic method was very useful for the determination of the site of contraction in one muscle. For example, in the rectus abdominis, the activity in the different segments which were divided from metameric point of view could be compared by the surface EMG's recorded from each segment, because increased force of contraction was reflected in the EMG's by increasing frequency and amplitude of the potentials.

In the present study, as described in the previous chapter, the abdominal viscera were divided into three groups on the basis of supplying three main arteries. Each group was stimulated with ACh solution injected into the pertaining artery to elicit the reflex muscular responses. Thus obtained EMG's were compared in general pattern and the dermatomes corresponding with abdominal viscera were illustrated in Fig. 18. In each of the three groups, the muscular contractions developed widely, including many segments of the abdominal dermatomes, i. e., Th7–Th11 in the upper abdonimal viscera, Th7–Th13 in the small intestine and Th 12–L 3 in the lower abdominal viscera. Therefore, they exhibited notable overlap in each other. The result agrees well with those reported by WATANABE who studied this problem with mechanical myograph on the divided rectus preparation.

To summarize the result of these experiments, it has been fairly well established by means of electromyographic method that the visceral "défense musculaire" widely appears on the abdominal wall muscles without showing the clear localisation as proved in many instances of the peritoneal "défense musculaire".

It is of interest to consider whether the contraction of the alimentary canal is necessary or not, to provoke the viscero-motor reflex. Concerning this problem, the present study showed that the alimentary canal contraction was not necessarily required to the reflex, since the contractions of intestine was not coincidental with rectus muscles when they developed and disappeared.

Recently, Ch. KIMURA and his co-workers have discovered a method of causing visceral pain with ACh. On the other hand, ARMSTRONG who studied on cutaneous sensibility, stated that ACh evoked a sharp pain in their cantharidin blister area on the skin. Accordingly, it seems reasonable to assume that ACh presents the same behaviour on the cutaneous and visceral sensory nerve endings, and that as the result of direct stimulation of intestinal nerve endings with ACh, the afferent impulses are evoked in the afferent pathway of viscero-motor reflex arc, having no direct relation to intestinal contraction.

Further considerations are continued by the two additional investigations: 1) when the physiological salt solution was injected into the artery instead of ACh solution, no responses were observed. 2) an injection of ACh into the occluded artery failed to give any reaction. These facts have led to the conclusion that the viscero-motor reflex provoked by the ACh method resulted from stimulation of the sensory nerve ending of the intestine itself, neither by mechanical pressure of the injected solution or from the blood vessel itself.

By the simultaneous recording of the four abdominal muscles, it was clearly demonstrated that each muscle of the abdominal wall contracted with almost the same intensity. This is explained from the fact that they are innervated by the same intercostal and lumbar nerves from the 6th to the 13th. Recently, Kosako of our laboratory who examined the viscero-motor reflex in the lower leg muscles, stated that in most tested animals the stimulation of abdominal viscera with ACh solution failed to elicit any responses in the lower leg muscles. The striking contrast between abdominal and leg muscle responses supports the Kimura's hypothesis that the "défense musculaire" of the leg which is innervated by L2-S2 segments of the spinal cord does not occur, because of the lack of the white rami between those segments.

It is of great interest that the periodic EMG of the lower part of the rectus muscle was recorded by the stimulation of the uterus. This suggests that the contraction may be one type of abdominal wall reaction associated with the labor pains.

Finally, the viscero-motor reflex arising from the abdominal blood vessels has been studied by electromyographic method with the cat after decerebration. In this experiment, it was proved that reflex could be elicited from the blood vessels by the electrical stimuli as well as by stimulating the viscera with ACh.

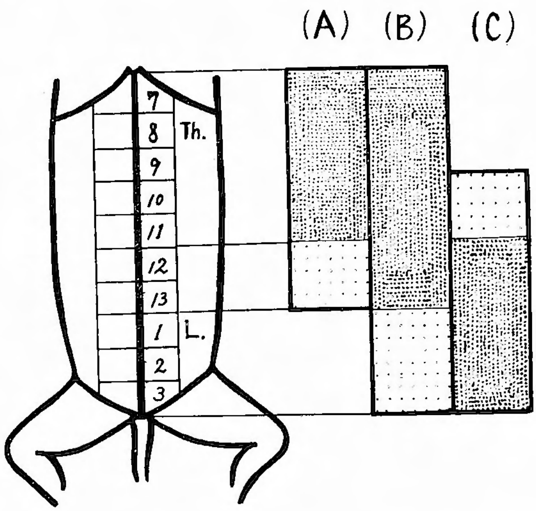


Fig. 19 shows the segments of "défense musculaire" (densely stippling) corresponding with the three main abdominal vessels respectively. (A) Th7-Th11: reflected from the celiac artery. (B) Th7-Th13: from the superior mesenteric artery. (C) Th12-L3: from the inferior mesenteric artery. These segments are decided by the EMG's of Figs. 15, 16, and 17.

The results obtained from the three main visceral arteries were compared with each other and illustrated in Fig. 19. The dermatomes reflected from these vessels, viz., Th7-T711 in the celiac artery, Th7-Th13 in the superior mesenteric artery, and Th12-L3 in the inferior mesenteric artery, respectively agree with the results obtained from the previously descreibed three groups of the abdominal viscera. Furthermore, these dermatomes agree with the spinal segments innervating the three vessels, which have been demonstrated on the pervious study of the vascular sensibility by the present author.

Hence, it is clearly recognized that the following four phenomena accord with each other upon the point of view of segmental innervation : 1) abdominal visceral innervation by the spinal cord 2) abdominal vascular innervation by the spinal cord 3) "défense musculare" from the abdominal viscera 4) "défense musculare "from the abdominal blood vessels.

V SUMMARY AND CONCLUSIONS

(1) The viscero-motor reflexes were studied on the decerebrate cats by means of electromyographic method. It was emphasized that the method was very useful for the purpose of analysing the reflex muscle responses.

(2) The abdominal dermatomes which corresponded with the viscera from the view-point of the viscero-motor reflex were electromyographically decided. From the result, it was obviously proved that the visceral "défense musculaire" widely appeared on the abdominal wall over many segments of dermatomes.

(3) The alimentary canal contraction had no direct relation to the visceromotor reflex. ACh injected into the visceral artery played a rôle as a direct stimulator on the sensory nerve endings of viscera, without stimulating those of the blood vessels. In relation to this problem, it was also verified that the volume of the injected solution did not give rise to pressure effect as mechanical stimulus.

(4) The powerful reflex responses were recorded in the external oblique, the internal oblique, the transversalis muscle as well as in the rectus abdominis muscle after visceral stimulation. This result presented the interesting problems as to the irradiation of the viscero-motor reflex.

(5) Periodic contractions of the rectus muscle, which suggested those of the labor pains, were recorded on the EMG by stimulating the pregnant cat's uterus.

(6) The reflex muscular contractions of the abdominal wall, having appropriate segmental distributions on abdominal dermatomes, could be provoked not only by stimulating the abdominal viscera but also the blood vessels such as the celiac, the superior mesenteric, and the inferior mesenteric arteries. Furthermore, it was noted that the segments of dermatomes which were reflected from the vessels showed the same distribution as those reflected from the viscera.

I wish to express my sincere thanks to Assist. Prof. Ch. KIMURA, M. D. of our clinic for his help and criticism throughout this work.

An abstract of this study has been reported by the author at the 57 Annual Meeting of the Japanese Surgical Association, in Tokyo, on Apr. 1–3, 1957, and at the 10. Annual Meeting of the Japanese Electromyogrphic Association, in Okayama, on Oct. 11–12, 1957.

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和文抄録

内臓運動反射の筋電図学的研究

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(1) 内臓運動反射によつて起る腹筋収縮を筋電図上に記録した．此の方法によつて従来の研究方法の不確実な点，或は非生理的な条件の総てを除く事が出来，従つて本研究の目的に極めて好都合であつた．

(2) 内臓と対応する腹筋収縮が腹壁皮膚分節の面から考察され，其の分布が決定された．之によつて内臓性腹筋緊張は局在性を示す事なく，多数の分節に跨つて広く現われる事が筋電図学的に明瞭に示された．

(3) 消化管の収縮は内臓運動反射の発現に対し直接的関係を有しない事が証明された．動脈内に注射されたアセチールコリンは血管の知覚終末を刺戟する事なく，内臓の知覚終末を直接刺戟して該反射を惹起するものと理解される．用いられた注射液量は機械的刺戟としての圧効果を示さなかつた．

(4) 内臓刺戟によつて全腹筋から筋電図が記録された．此の事実は内臓運動反射の放散という現象に興味ある問題を提供する．

(5) 妊娠猫の左側子宮動脈へアセチールコリン溶液を注入して，同側の腹直筋下部から撰択的に週期性筋収縮を記録し得た．

(6) 腹腔内血管を電気刺戟する事により腹直筋より筋放電を記録し得た．筋収縮の腹壁皮膚分節上の分布はアセチールコリンを使用した内臓性反射の其れと一致する．